SLAC PROPOSAL NO. E-129
Received Dec. 27, 1976

A Study of $\bar{p}p$ Annihilations Using LASS

Bruce Barnett, David Blockus, Chih-Yung Chien,
Leon Madansky, Aihud Pevsner, Craig Woody, and Richard Zdanis

The Johns Hopkins University
Baltimore, Maryland 21218

A Study of $\bar{p}p$ Annihilations Using LASS

Bruce Barnett, David Blockus*, Chih-Yung Chien,
Leon Madansky, Aihud Pevsner, Craig Woody*, and Richard Zdanis

The Johns Hopkins University
Baltimore, Maryland 21218

SUMMARY

We propose to study $\bar{p}p$ annihilations between 8 and 13 GeV/c to measure multiplicities, their correlation moments and the annihilation cross section at two energies. Annihilations into exclusive channels (4π, $2K2\pi$, 6π, $2K4\pi$) and inclusive productions of K, π, and $K\bar{K}$ will be studied. Production limits of D and new particles will also be measured.

We require the LASS system with its on-line data acquisition system. The hydrogen target and separated beam 20-21 will be used. We need three weeks of check out time at low pulse rate (20 pps) and 100 hours of running time (at 180 pps equivalent) to collect a total of $\sim$ 4M triggers.

About 250 hours of Triplex time are needed for this experiment and the rest of the data analysis will be done on the XDS Sigma 7 and SEL 32/55 systems at Johns Hopkins.

---

*Graduate Students

A Study of $\bar{p}p$ Annihilations Using LASS

I. Introduction

The study of the annihilation of the proton-antiproton system into mesons has long been an interesting and important area in hadron interactions since it is a system with $B = S = Q = 0$; thus there is no quantum number selection rule here and any new states can be produced in pairs. The process is very different from ordinary hadron collisions thus one can expect to obtain rich information not available elsewhere.

However, because the annihilation process is very different from other hadronic processes (which are mostly peripheral) it requires apparatus with very large solid angle coverage. This has restricted most of the studies to bubble chambers so far. On the other hand, due to the lack of quantum number selections, the number of final states is very large which means good particle identification is needed to identify each final state. Very high statistics are also needed to obtain enough events for a given final state. Both of these requirements are incompatible with the limitations of traditional bubble chambers. For these reasons, data on $\bar{p}p$ annihilations have been very scarce and studies of $\bar{p}p$ annihilation processes have often been frustrated.

LASS is a spectrometer (Fig. 1) with near 4π solid angle coverage, good particle identification and a very high data acquisition rate; thus, time is right for a high statistics study of the $\bar{p}p$ annihilations. We propose to use this facility to do a high statistics experiment ($\sim$ 200 events/μb) with modest running time (100 hrs. at 180 pps) to study $\bar{p}p$ annihilation between 8 and 13 GeV/c.

II. Physics Motivation

The motivation for the study of $\bar{p}p$ annihilation process is two-fold: to study the dynamics of hadrons and to search for new particles. As we discussed above, the $\bar{p}p$ system is eminently suitable for both purposes.

The abundant and important results from recent e^+e^- annihilation experiments have many interesting connections to $\bar{p}p$ annihilations. For instance, annihilations of e^+e^- and $\bar{p}p$ demonstrate remarkable resemblance despite the fact that e^+e^- systems are definite $J^P = 1^-$ state with point-like particles while $\bar{p}p$ systems are mixed J^P states of extended objects.(1,2) Existing data on $\bar{p}p$ annihilation cross sections seem to have the same energy dependence as e^+e^- annihilation to hadrons and the magnitude seems to agree with calculations based on a simple vector dominance model(3) (Fig. 2). In addition to similarities in gross features, there are also remarkable resemblances in some specific channels. For instance, the $\pi^+\pi^-$ mass spectra in $2\pi^+2\pi^-$ states from $\bar{p}p$ and e^+e^- annihilations are shown(1) to be almost identical (Fig. 3). Studies on these, and other states at higher energies will shed more light on these similarities and on the nature of annihilation interactions. Comparisons of multiplicities and their moments will also provide more information. The study of production of K mesons in $\bar{p}p$ annihilation is of extreme interest. The inclusive transverse momentum distributions and the correlations between the K and $\bar{K}$ mesons will provide interesting comparisons again with the results from e^+e^- annihilations.

The difference in $\bar{p}p$ and pp total cross sections is often attributed to $\bar{p}p$ annihilations (Fig. 4). Regge models describe the $\bar{p}p$ and pp cross sections with P, ρ, ω, f and A_2 exchanges, thus giving the difference in total cross sections as

$$\Delta\sigma_T = \sigma_T(\bar{p}p) - \sigma_T(pp) = 2\ \mathrm{Im}(\rho + \omega)_{t=0}$$

which gives an energy dependence of $\Delta\sigma$ as $\sim S^{\alpha_V(0)-1} \sim S^{-0.5}$. In fact this agrees with the data very well. It is not clear whether the $\bar{p}p$ annihilation cross section follows the same energy dependence$^{(4)}$. It can be seen from Fig. 4 that although the data between beam momenta 1 to 5 GeV/c seem to agree with $\Delta\sigma_T$, data at higher momenta with better accuracy are clearly needed to clarify the situation. Studies with clean data on multiplicities and correlation moments will again yield important results.

There has been much interest in high P_T processes recently but their origin is still not clear. It is well known that hadrons from $\bar{p}p$ annihilation process have higher values$^{(5)}$ of $<P_T>$ than the non-annihilation processes. (Fig. 5)$^{(1)}$. Many explanations are possible: multiperipheral baryon exchange, production of heavy resonances, small impact parameters -----etc. Clean data with high statistics can again shed light on this high P_T process.

Recent results from e^+e^- annihilations have rekindled the interests in the search for new particles. For example, the discovery of the D meson in e^+e^- annihilations naturally leads one to search for it in hadron collisions. Estimates of its production in hadron collisions vary anywhere between a few nb to a few μb. A definitive experimental measurement is clearly needed. So far all the searches in hadron collisions have been limited to two body decays yielding upper limits of cross section times branching ratio at $\sim 1\ \mu b^{(6,7,8,9)}$. A high statistics study with large solid angle coverage and good particle identification will greatly raise the sensitivity.

III. Experimental Set up and Acceptance

We plan to use the entire LASS system in conjunction with the RF separated beam 20-21 providing separated antiprotons up to 13 GeV/c. Two Cerenkov counters before the target tag the K and π contaminations in the beam. Measurements of the incident momentum ($\Delta P/p \sim 0.5\%$) and trajectory ($\Delta\theta \sim 0.5$ mr, $\Delta X \sim 0.5$ mm) will be provided by scintillation hodoscopes and proportional wire chambers.

We will use the LASS system in the form shown in Fig. 1. The features particularly important to this experiment will be the large solid angle, good momentum resolution, good particle identification, fast data acquisition rate and the versatile triggers.

The solenoid and the dipole spectrometers provide better than $\Delta P/p = 2\%$ momentum resolution over essentially the entire solid angle except those rare tracks in the backward direction in the laboratory and those with very high momentum at 90^o ($P_T > 2$ GeV/c, $P_L < 1$ GeV/c.) (Fig. 6).

The charged particle identification will be provided by C1 (the 38 element gas Cerenkov counter at the end of the solenoid), TOF (the 24 element time of flight scintillation hodoscope mounted on C1) and C2 (the high pressure gas Cerenkov counter at the downstream end of LASS). Counter C1 filled with Freon 114 at one atmosphere provides π/K separation between 2.7 and 9.5 GeV/c; C2 filled with Freon 12 at 3 atmospheric pressure provides π/K separation between 1.6 and 5.7 GeV/c and K/p separation above 5.7 GeV/c; and the TOF hodoscope gives good $K/\pi/p$ separation below 1.6 GeV/c, K/p separation up to 2.1 GeV/c and π/p separation up to 2.5 GeV/c.

C2 is important to identify $\bar{p}$ production. It has an aperture of 1m x 2m at ~ 13m from the target, thus can reject antiprotons produced with $|t| \lesssim 0.5\ (\mathrm{GeV/c})^2$. Assuming $\frac{d\sigma}{dt} \sim e^{-5t}$ for inclusive $\bar{p}$ production, it can veto 90% of the $\bar{p}$ production.

The cross section for inclusive $\bar{p}p \rightarrow \bar{n}x$ production is comparable to that of the annihilation process, thus we need to have an anti-neutron detector to tag events with forward antineutrons. Fig. 7 shows the schematics of the assembly which consists of a scintillator A, a photon counter S_1, steel plate Fe, shower counter S_2 and wire chamber W. Counter A tags charged particles; S_1 has ~ 4 radiation lengths which gives large pulse heights for 98% of photons and none for a non-interacting $\bar{n}$. The Pb/Fe - scintillator sandwich S_2 is expected to give no signal for photons and large signals for most $\bar{n}$ since it is placed behind one absorption length of steel Fe. Wire chambers W may be added to give a crude measurement of the center of the hadron shower due to $\bar{n}$ interactions which can be used to correct for geometrical acceptance. In this configuration, a photon will give a signal $\gamma = \bar{A}\cdot S_1\cdot \bar{S}_2$, while an antineutron will give a coincidence NBAR = $\bar{A}\cdot\bar{S}_1\cdot S_2$ with ~ 65% efficiency. An antiproton will yield a signal PBAR = $A\cdot\bar{C}_2\cdot\bar{S}_1\cdot S_2$ which can be used to calibrate the $\bar{n}$ veto detector assembly. An extra Fe WS_2 module may be added at the downstream end if it is deemed necessary from the checkout run. The detector will have a cross section of 2m wide and 1m high to match the aperture of C_2.

C_1 and TOF are important for the identification of pions and kaons. Their acceptance is very good for particles produced in the forward hemisphere and at $X \simeq 0$ (Figs. 8a and b). The acceptance of C_1 and TOF for particles produced in the backward hemisphere with large P_T is poor, but tracks are well reconstructed, as shown by the kinematics curves for inclusive production of pions, kaons and protons (Figs. 9a,b,c,). These are tracks with low momenta in the laboratory.

The LASS on-line data acquisition system allows IBM 370/168 time for a software trigger. Software triggers may be developed from the checkout run to assist rejection of $\bar{p}$ and $\bar{n}$ events.

IV. Trigger

LASS can run with several different triggers at preset ratios which is very useful to study systematics, background, and losses. The beam Cerenkov counters and hodoscopes define the signal B for a good $\bar{p}$ beam particle incident on the target. The "lollipop" counter L in the beam trajectory in front of C_2 signals the exit of a non-interacting beam track. The annihilation signal is given in terms of the PBAR and NBAR signal defined in the last section

$$\mathrm{ANN} = \overline{\mathrm{PBAR}} \cdot \overline{\mathrm{NBAR}}.$$

Some of the triggers we will be using are

Trigger	Signal	Interaction
annihilation	$B \cdot \bar{L} \cdot \mathrm{ANN}$	$\bar{p}p \rightarrow$ annihilation
$\bar{p}$	$B \cdot \bar{L} \cdot \mathrm{PBAR}$	$\bar{p}p \rightarrow \bar{p}\ X$
$\bar{n}$	$B \cdot \bar{L} \cdot \mathrm{NBAR}$	$\bar{p}p \rightarrow \bar{n}\ X$
interaction	$B \cdot \bar{L}$	$\bar{p}p \rightarrow X$
beam track	BL	

Since we are studying a large fraction of the total cross section (~ 15 out of 60 mb), we do not need to define very tight triggers. In fact, we will take all of the annihilation triggers and some fraction of $\bar{p}$ and $\bar{n}$ triggers. This will allow careful study on various systematic effects, e.g. acceptance, efficiency, background, zero prongs ..... etc. Details of these triggers will be based on the data from the check out runs.

V. Running Time and Event Rate

We will require about three weeks at low pulse rate (~ 20 pps) to check out the triggers. Detection of antineutrons will be checked with antiprotons using S_2, W and a small module for A, S_1 and Fe in Fig. 7. After equipment is checked out, we will need 100 hours of running time (at 180 pps equivalent) to run Beam 20-21 to deliver 1 $\bar{p}$/pulse at 8.2 and 13 GeV/c. The beam momentum of 8.2 GeV/c was chosen to clarify the comparison of $\bar{p}p$ annihilation with e^+e^- annihilation into hadrons at $\sqrt{S} = 4.1$ GeV. (Fig. 2). The momentum 13 GeV/c gives the highest attainable energy.

Assuming that we trigger on all of the annihilation cross section ($\sim$ 15 mb), 20% of $\bar{p}p \rightarrow \bar{p}\, X$ inelastic scattering and 40% of $\bar{p}p \rightarrow \bar{n}\, X$ cross section, we will have a triggered cross section of 25 mb. This yields 2M triggers (a sensitivity of 100 ev/μb) at each energy.

VI. Sensitivity and Background

With a sensitivity of 100 ev/μb, measurement accuracies are clearly limited by background corrections. The large amount of both annihilation and non-annihilation data available in this run will allow a detailed understanding of background from non-annihilation processes. The high statistics also allows us to use C-invariance to further correct the data (e.g. forward K^- should behave the same as backward K^+); this will improve the accuracies in cross section section-related measurements.

The sensitivity of new particle searches depends on the geometrical acceptance and the particle identification efficiency. While the acceptance for any charged particle is nearly 100%, the efficiency of particle identification depends on the kinematics and dynamics of the production of new particles. For instance, the acceptance for the identification of the decay of a D meson into charged particles in reaction $\bar{p}p \rightarrow \bar{D}D$ is 5 $\sim$ 50% depending on the production mechanism, decay modes and requirements for particle identifications. (This neglects detector inefficiencies, e.g., small signals in C_1 for tracks with small P_L.) We will study the depndence of mass spectra in the D region for various signatures (e.g., P_T, $K^\pm$, K^0, μ, multiplicities .... etc.). These results should yield data for possible future runs for new particle searches.

VII. Computing and Data Analysis

We will require the on-line data link to the Triplex for data acquisition, sampling and monitoring. Since we will be exploring the full hardware potential of LASS and the software system will still be evolving when the data of this experiment is taken, we plan to work closely with the staff of LASS group during the early stages of the data analysis. For this purpose, we plan to analyze the first 20% of the data with the Triplex system. This, together with data laundering for the rest of the data, will require 250 hours of the Triplex time.

The analysis of the bulk of the data will be done at Johns Hopkins. We have been collaborating with SLAC Group B and Caltech in the past few years to construct and set up the LASS system. We implemented a preliminary version of the LASS analysis program at Hopkins a year ago and demonstrated that it is possible for a University group to do LASS analysis work on their home computers. We have an SDS Sigma 7 and a new SEL 32/55 system. Each of them has a speed of ~ 1/10 of Triplex and will have a memory of up to 128K words. We have already set up and run Monte Carlo and geometry programs on the Sigma 7 system and established benchmarks. The new SEL 32/55 system and the expanded memory have been acquired in anticipation of data from this experiment.

VIII. Summary

We plan to use LASS to study $\bar{p}p$ annihilations into mesons between 8 and 13 GeV/c. We require 100 hours (180 pps equivalent) of running and about three weeks check out time at 10-20 pps. This will yield 4M events for a high statistics survey study of $\bar{p}p$ annihilations. Among the topics that will be studied are:

1. To measure multiplicities and their correlation moments, and $\bar{p}p$ annihilation cross section at two energies.
2. To study $\bar{p}p$ annihilations into exclusive channels (4π, $2K2\pi$, 6π, $2K4\pi$).
3. To study inclusive K, π, and $K\bar{K}$ productions, their P_T, y, and energy behaviors.
4. Measure the production limits of D and new particles to provide information for future very high sensitivity search for new particles in $\bar{p}p$ annihilations.

References

1. H. Muirhead, Proceedings of the International Symposium on $\bar{p}p$ Interactions, Loma-Kali, Finland 1975.
2. G. Eilam et al., Nuovo Cimento Letters 14, 108 (1975).
3. C. A. Nelson, Nuovo Cimento Letters 11, 517 (1974).
4. P. S. Gregory, Proceedings of the International Symposium on $\bar{p}p$ Interactions,
5. Some recent results of Raja et al. (Fermilab-Pub-76/79-Exp. 7200.311) from the 100 GeV/c $\bar{p}p$ data seem to show that $<P_T>$ for inclusive π^o production is smaller in $\bar{p}p$ collisions than that in pp collisions Whether this result holds for $\bar{p}p$ annihilation relative to pp interactions remains to be seen.
6. K. Bunnell et al. PRL 37, 85 (1976).
7. D. Bintinger et al., Proceedings for the 1976 Vanderbilt Conference on Particle Searches and Discoveries. (AIP Conference Proceedings No. 30) p. 30.
8. M. A. Ablins et al., ibid. p. 102.
9. R. Cester et al., PRL 37, 1178 (1976).

Figures

1. Schematic layout of LASS.
2. Comparison of energy dependence of $\bar{p}p$ and e^+e^- annihilations. (from Ref. 1).
3. Mass distributions of $\pi^+\pi^-$ in $\bar{p}p \rightarrow 2\pi^+2\pi^-$ and $e^+e^- \rightarrow 2\pi^+2\pi^-$. (from Ref. 1)
4. $\sigma(\bar{p}p \rightarrow \text{annihilation})$ compared with $\Delta\sigma_T = \sigma_T(\bar{p}p) - \sigma_T(pp)$. Cross sections were multiplied by $P_{lab}^{0.64}$ to remove the energy dependence in $\Delta\sigma_T$. (from Ref. 4)
5. $<P_T>$ for annihilation and non-annihilation processes. (from Ref. 1)
6. Momentum resolutions of LASS.
7. Schematics of the anti-neutron detector.

8a. 8b. Acceptance of C_1 calculated at 10 GeV/c for p and K respectively. (Acceptance for π is similar to that for K).

9a. 9b. 9c. Kinematics of 10 GeV/c $\bar{p}p$ interactions for inclusive productions of π, K, and p, respectively.

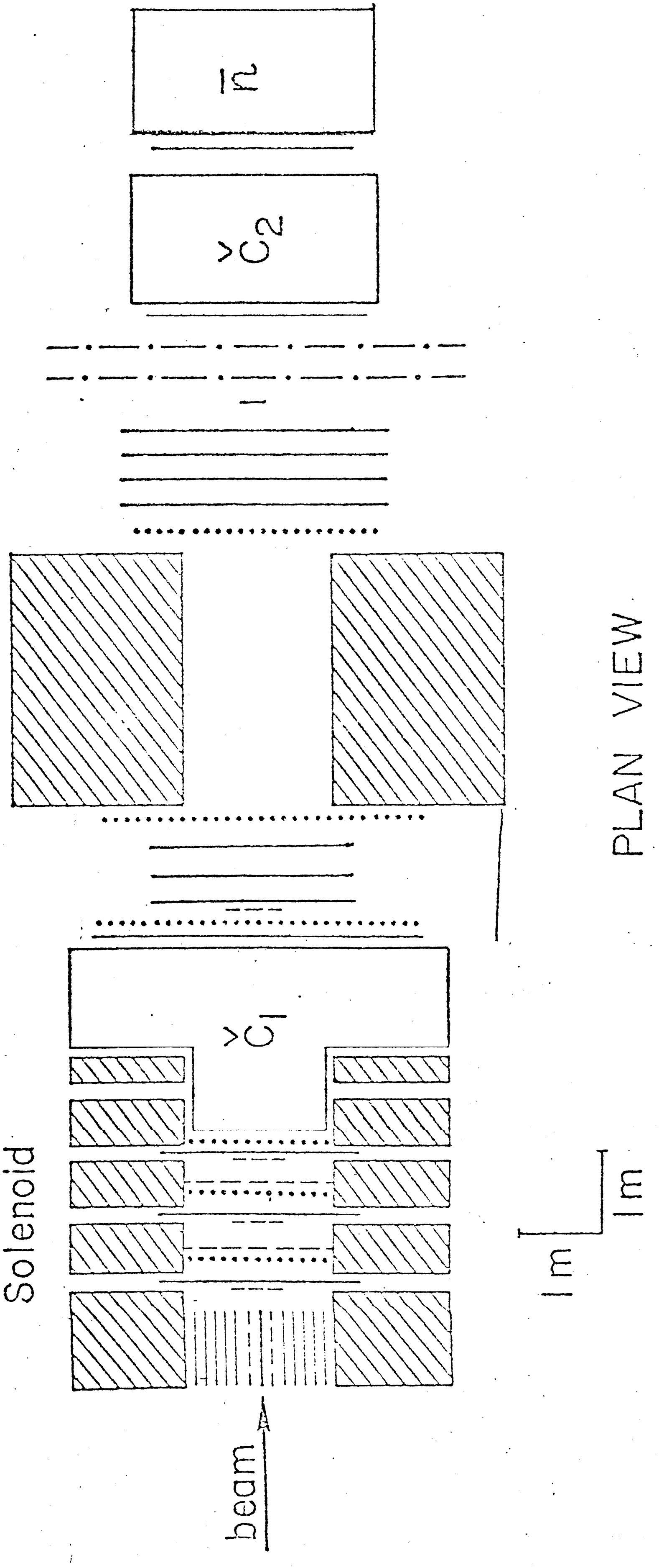


Figure 1

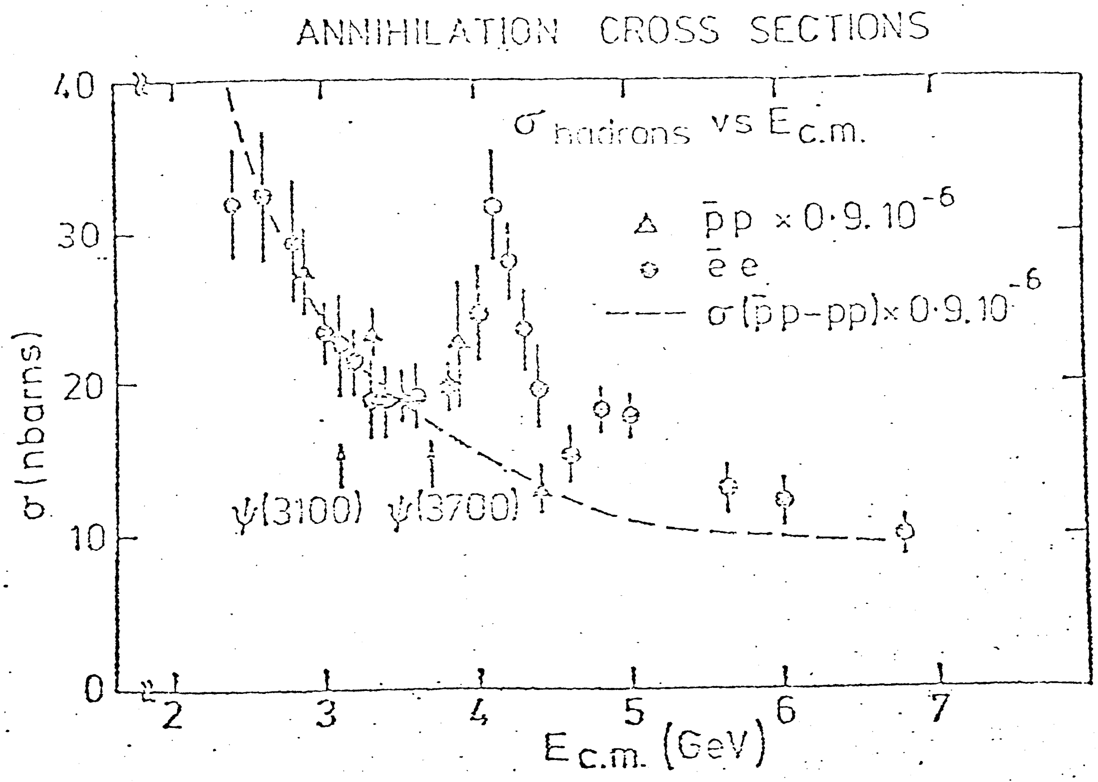
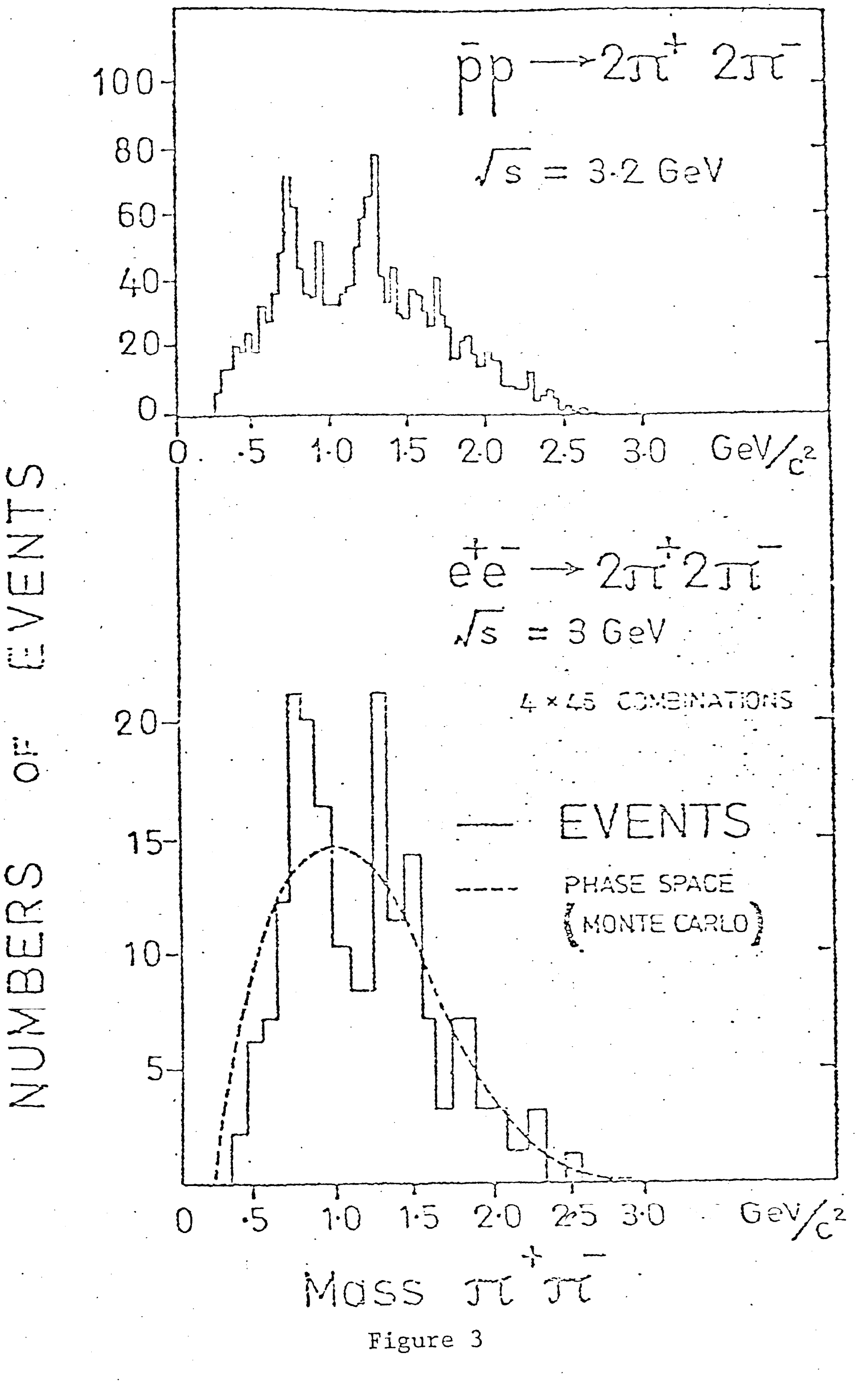

ANNIHILATION CROSS SECTIONS
σ_{hadrons} vs $E_{\text{c.m.}}$
△ $\bar{p}p \times 0.9.10^{-6}$
○ $\bar{e}e$
--- $\sigma(\bar{p}p-pp)\times 0.9.10^{-6}$
ψ(3100)
ψ(3700)
σ (nbarns)
0
10
20
30
40
2
3
4
5
6
7
$E_{\text{c.m.}}$ (GeV)

Figure 2



$\bar{p}p \rightarrow 2\pi^+ 2\pi^-$
$\sqrt{s}$ = 3·2 GeV
100
80
60
40
20
0
0 ·5 1·0 1·5 2·0 2·5 3·0 GeV/c²
NUMBERS OF EVENTS
$e^+e^- \rightarrow 2\pi^+ 2\pi^-$
$\sqrt{s}$ = 3 GeV
4 × 45 COMBINATIONS
20
15
10
5
EVENTS
PHASE SPACE (MONTE CARLO)
0 ·5 1·0 1·5 2·0 2·5 3·0 GeV/c²
Mass $\pi^+\pi^-$

Figure 3

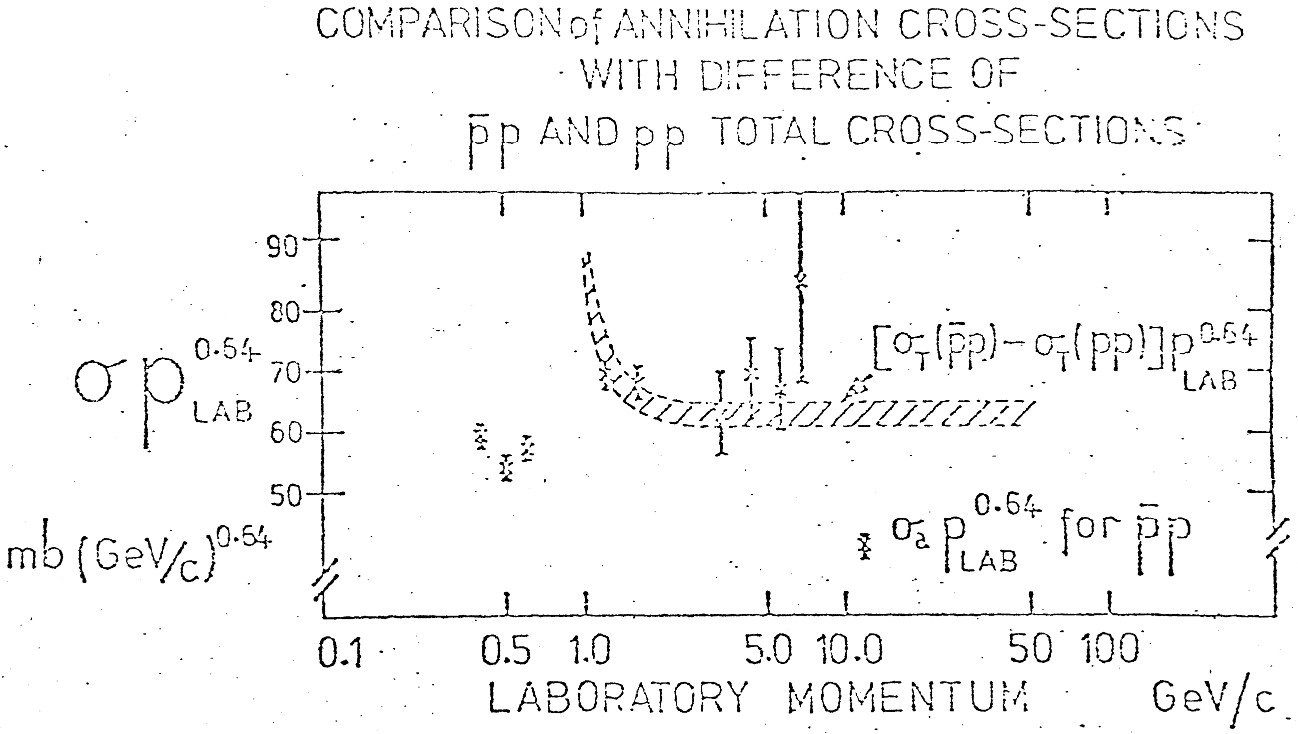
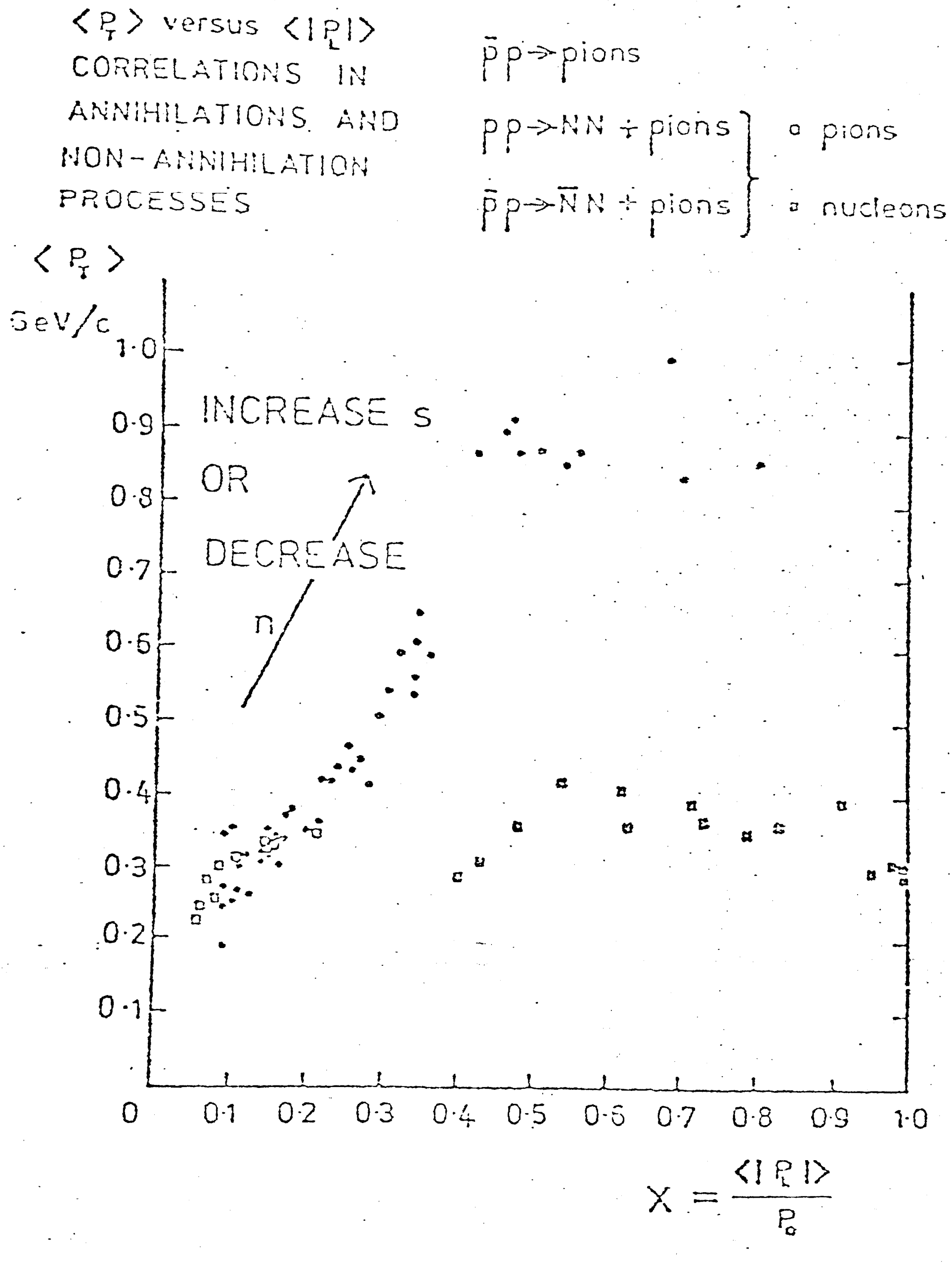

COMPARISON of ANNIHILATION CROSS-SECTIONS WITH DIFFERENCE OF $\bar{p}p$ AND pp TOTAL CROSS-SECTIONS
$\sigma p_{LAB}^{0.64}$
$mb(GeV/c)^{0.64}$
90
80
70
60
50
$[\sigma_T(\bar{p}p)-\sigma_T(pp)]p_{LAB}^{0.64}$
$\sigma_a p_{LAB}^{0.64}$ for $\bar{p}p$
0.1
0.5
1.0
5.0
10.0
50
100
LABORATORY MOMENTUM GeV/c

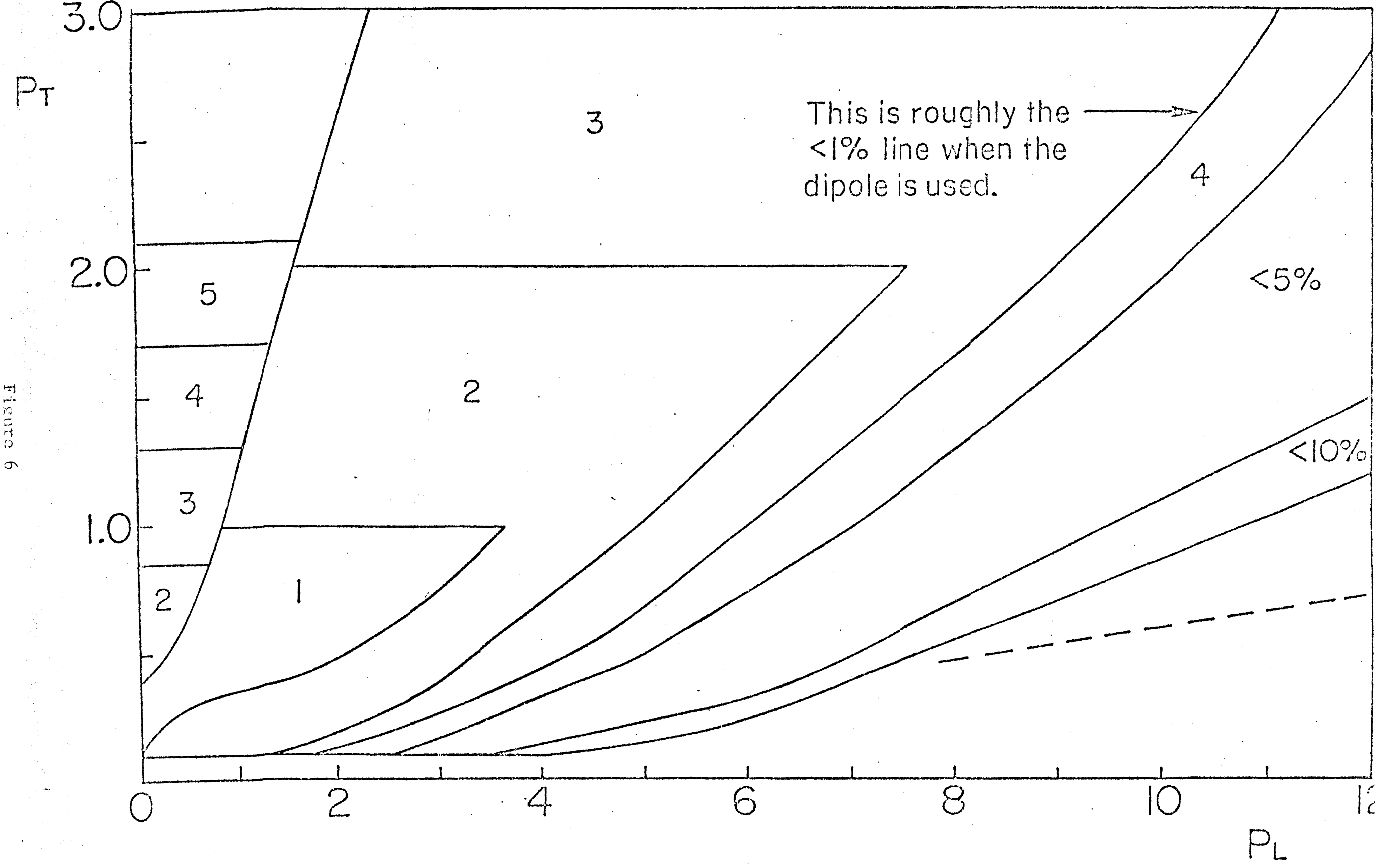
Figure 4



⟨P_T⟩ versus ⟨|P_L|⟩
CORRELATIONS IN
ANNIHILATIONS AND
NON-ANNIHILATION
PROCESSES
p̄p → pions
pp → NN + pions
p̄p → N̄N + pions
▫ pions
▫ nucleons
⟨P_T⟩
GeV/c
1·0
0·9
0·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
0
INCREASE s
OR
DECREASE
n
0·1
0·2
0·3
0·4
0·5
0·6
0·7
0·8
0·9
1·0
X = ⟨|P_L|⟩ / P_0

Figure 5

Momentum Resolution of the Solenoid ($\Delta p/p\,\%$)



This is roughly the <1% line when the dipole is used.

Figure 6

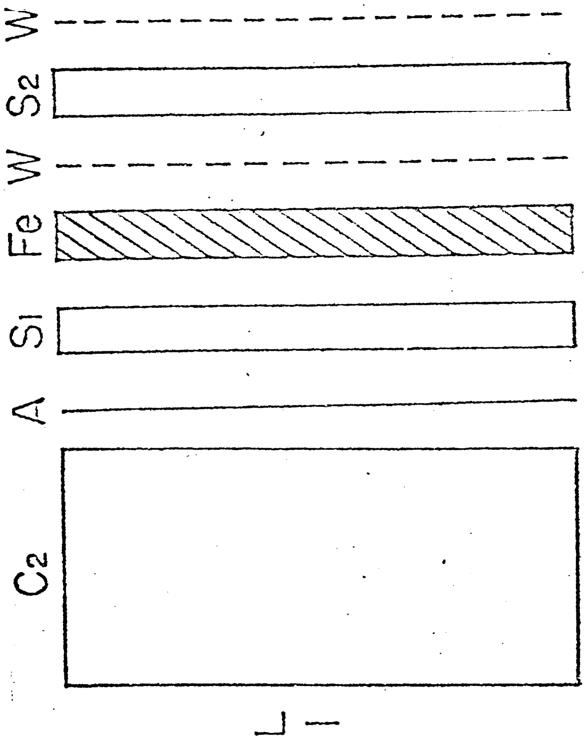


Figure 7

Acceptance at C1

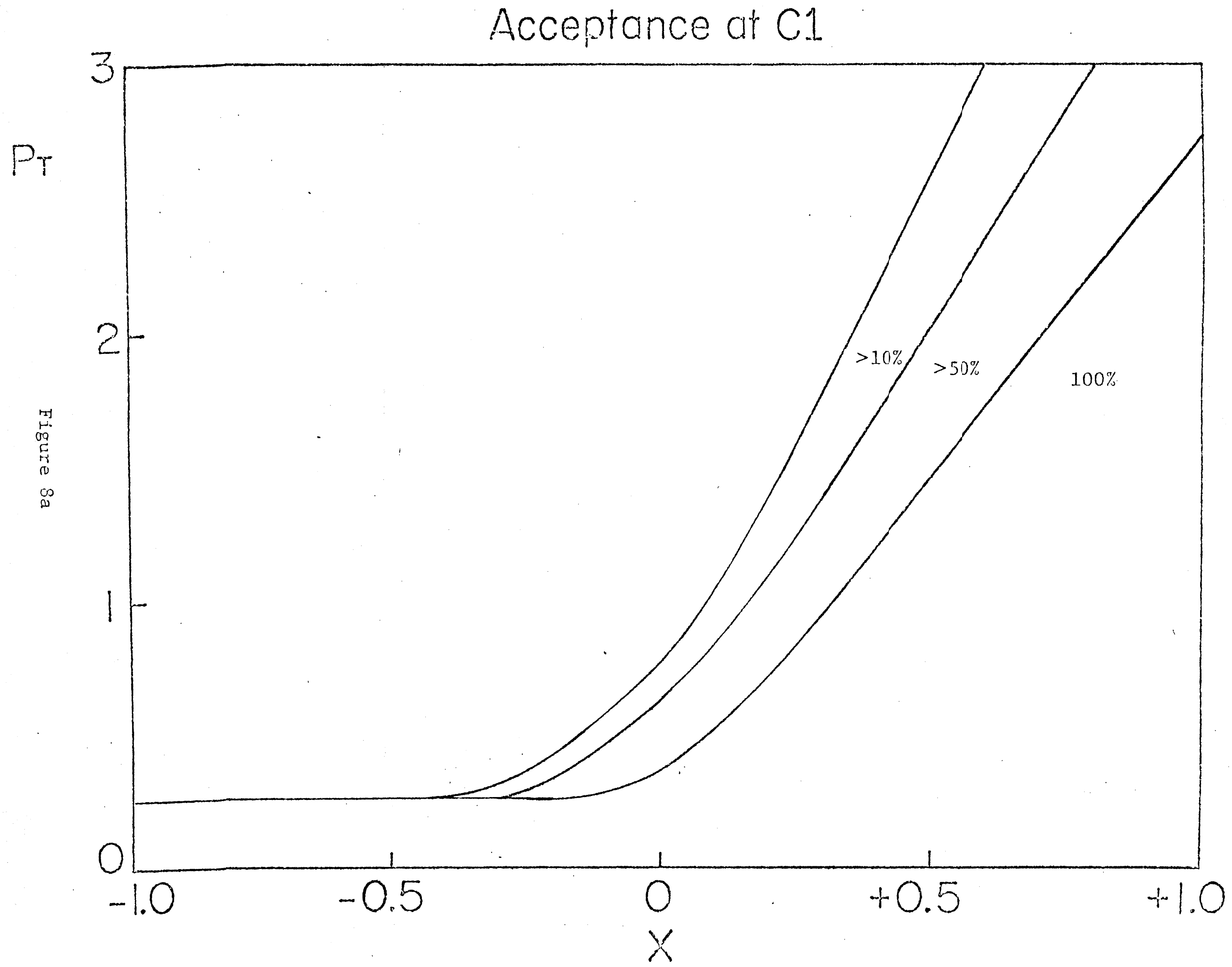


Figure 8a

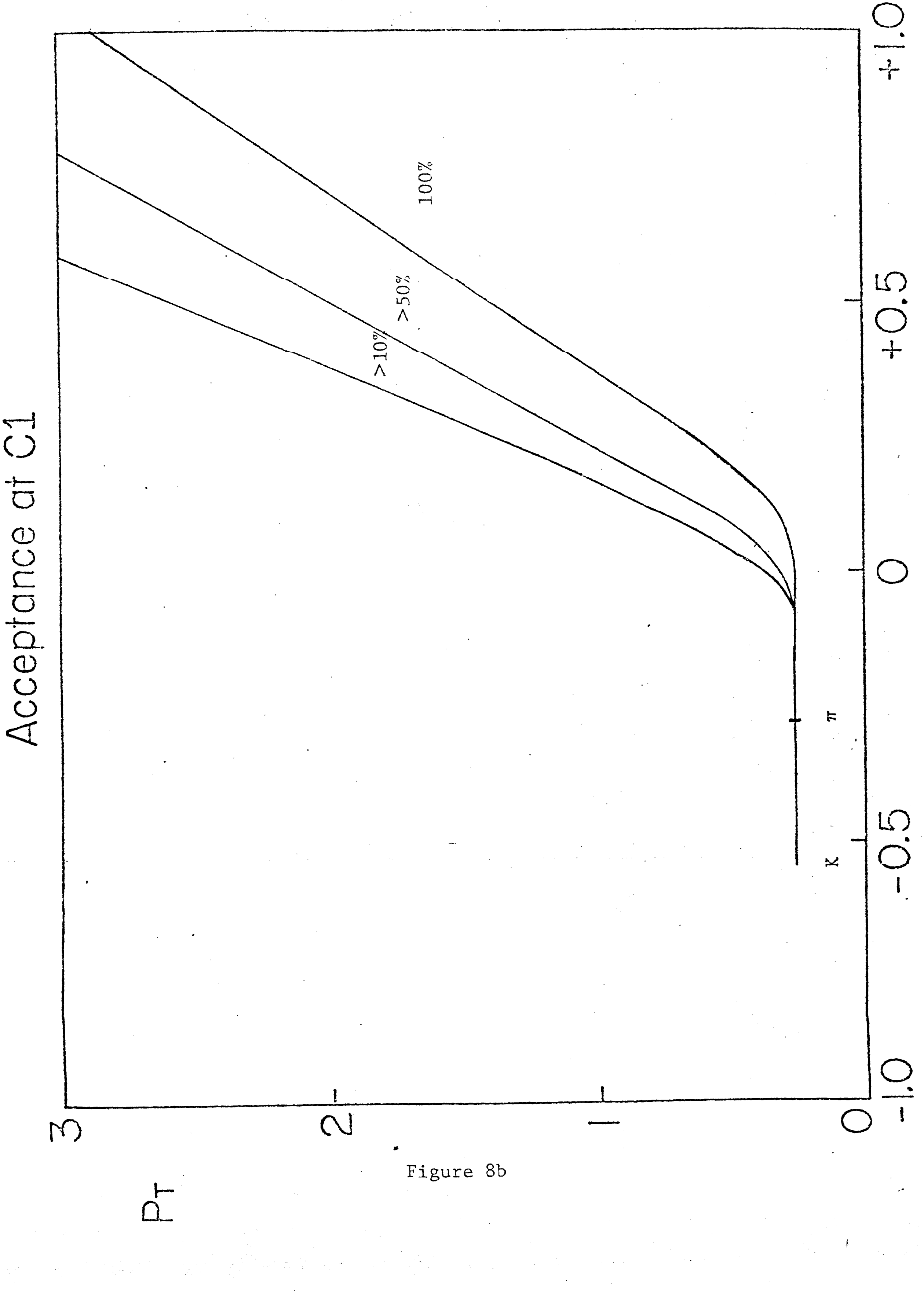


Figure 8b

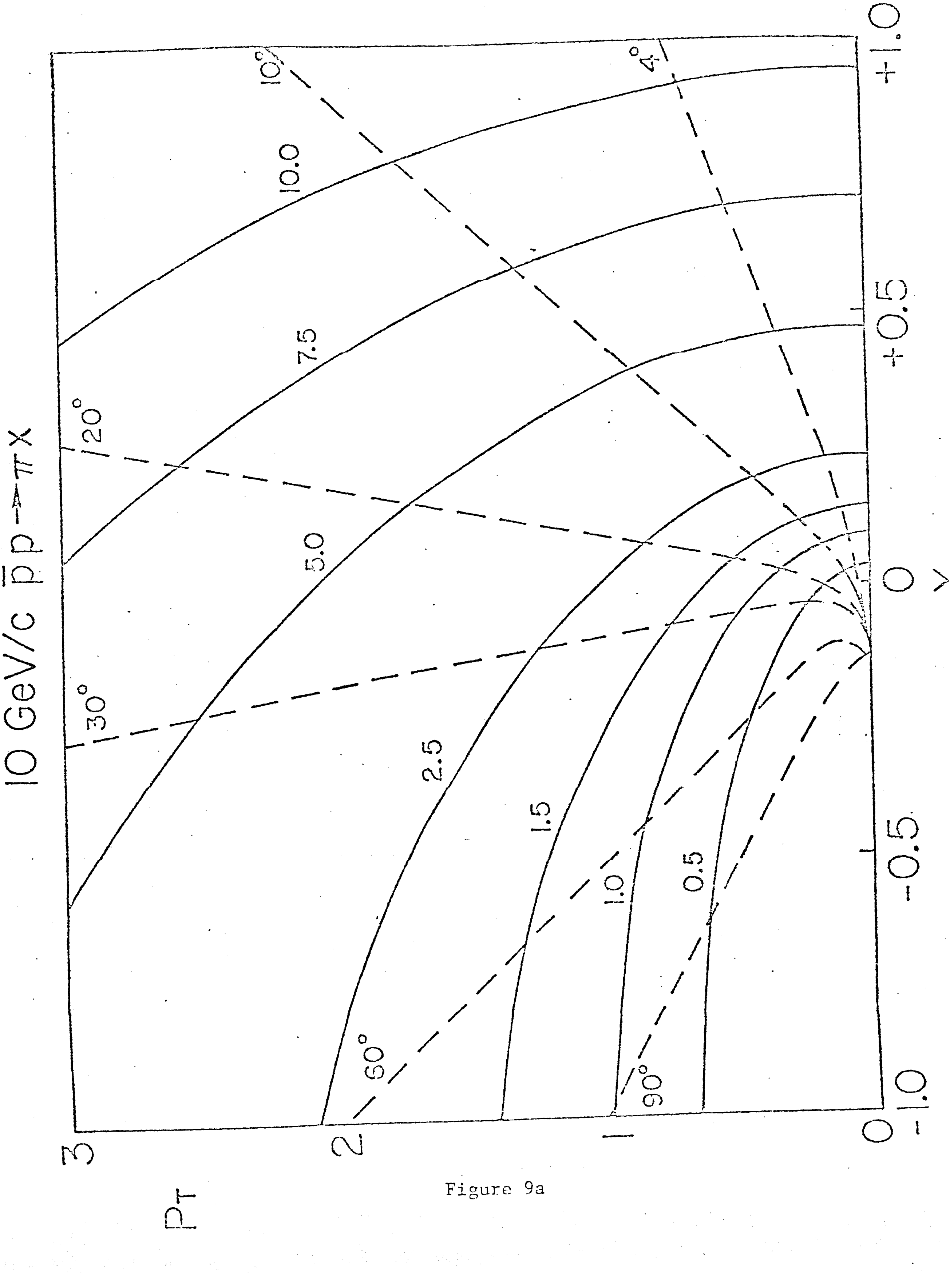

10 GeV/c $\bar{p}p \rightarrow \pi X$
P_T
X
0
1
2
3
-1.0
-0.5
0
+0.5
+1.0
10.0
7.5
5.0
2.5
1.5
1.0
0.5
4°
10°
20°
30°
60°
90°

Figure 9a

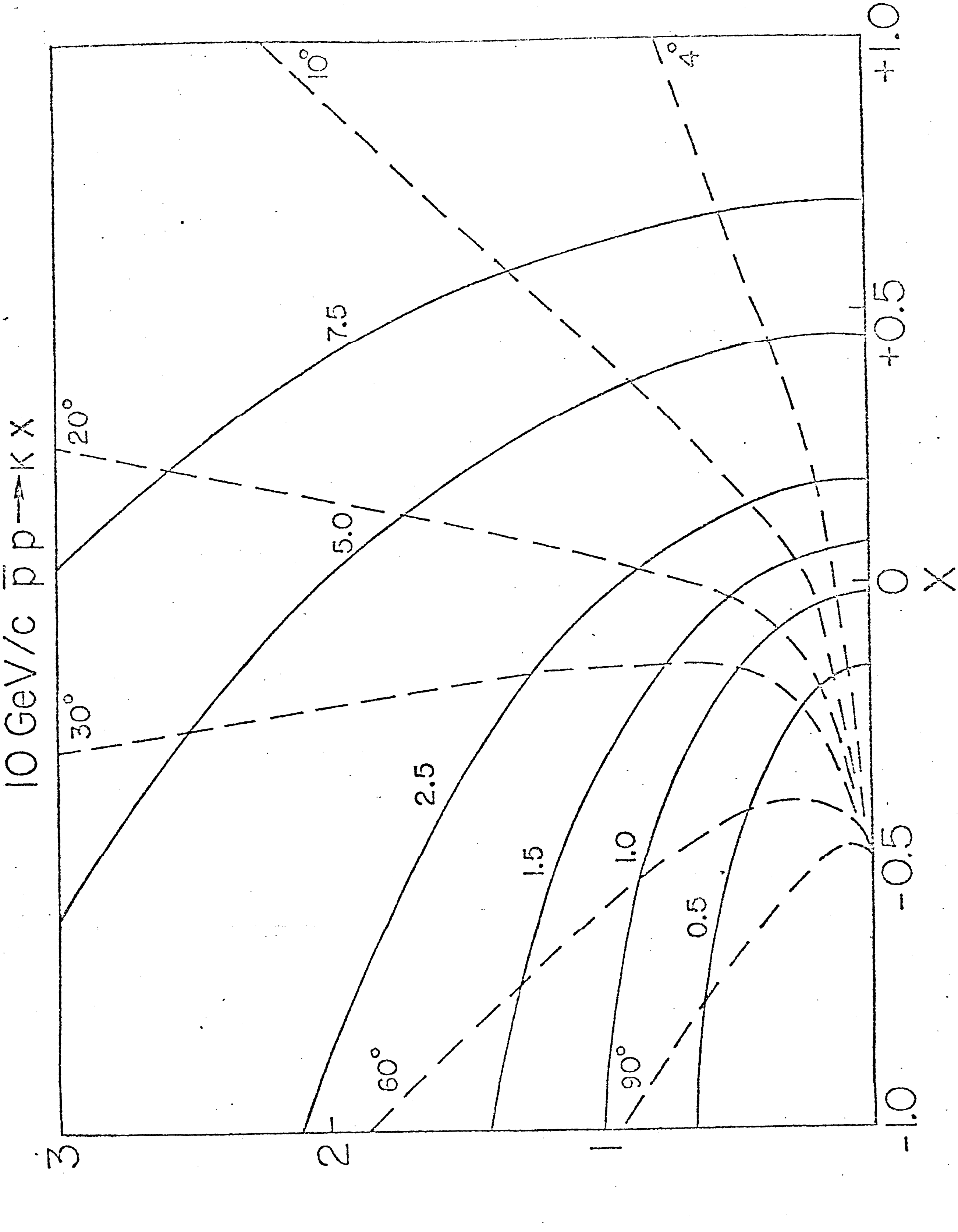

10 GeV/c $\bar{p}p \rightarrow K X$
7.5
5.0
2.5
1.5
1.0
0.5
4°
10°
20°
30°
60°
90°
3
2
1
−1.0
−0.5
0
+0.5
+1.0
X
P_T

Figure 9b

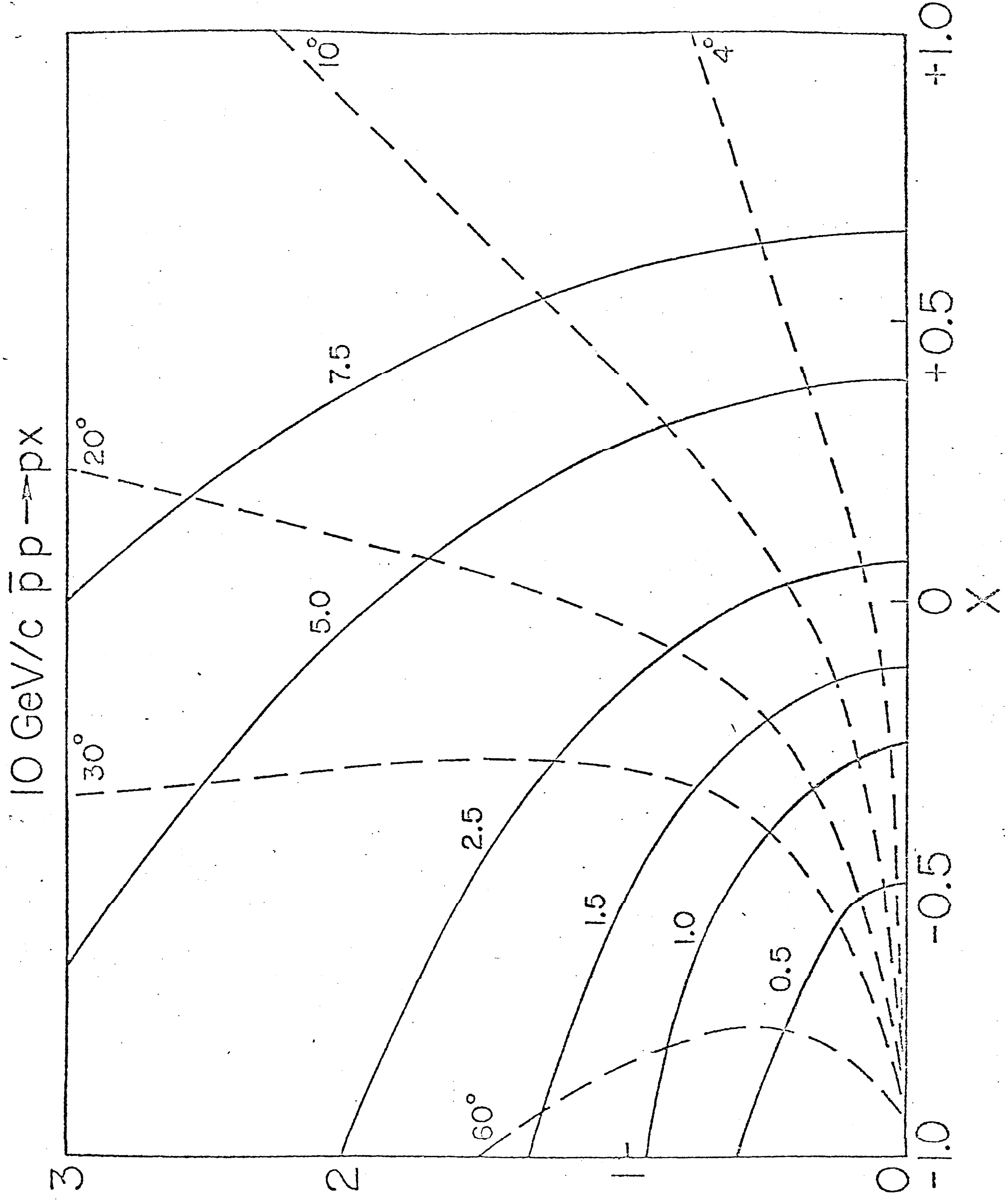

10 GeV/c $\bar{p}p \rightarrow pX$
P_T
3
2
1
0
X
-1.0
-0.5
0
+0.5
+1.0
0.5
1.0
1.5
2.5
5.0
7.5
60°
30°
20°
10°
4°

Figure 9c